PEEM analysis of the wear debris of the silicon-incorporated diamond-like carbon films tribo-tested in vacuum

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INTRODUCTION

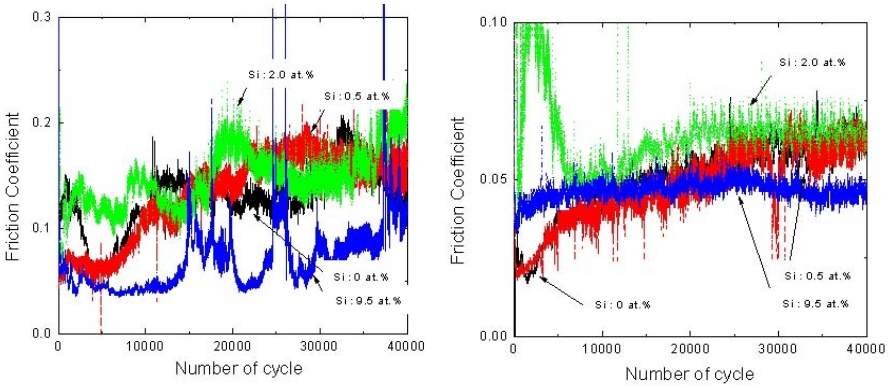
Diamond-like carbon (DLC) film is an excellent wear resistant material and the properties of DLC films were found to be improved by silicon incorporation [1-2]. Tribological behavior of a DLC film is strongly dependent on the test environments such as relative humidity or vacuum. Silicon addition into DLC film enhances mechanical properties including hardness and Young's modulus and also improves friction behavior [2-4]. Debris formed in wear test was found to have an important role in varying the friction coefficient [5]. For the Si-incorporated DLC films debris formation and friction behavior was investigated with photoemission electron microscopy (PEEM) at the ALS.

EXPERIMENT

Silicon-incorporated DLC films were deposited on p-type Si(100) wafers using the r.f –PACVD method [3-5]. The friction test was done with a rotating-type ball-on-disk tribometer in vacuum and dry air atmosphere. The applied normal load between the steel ball and the DLC films was between 1.96 N to 9.8 N during sliding the ball on the films. After the tribo-test, the Si-incorporated DLC films were placed in the PEEM II at the ALS beam-line 7.3.1.1. The morphologies of debris on the track were imaged with PEEM and the carbon K edge NEXAFS spectra of the debris and the DLC films were measured.

RESULTS

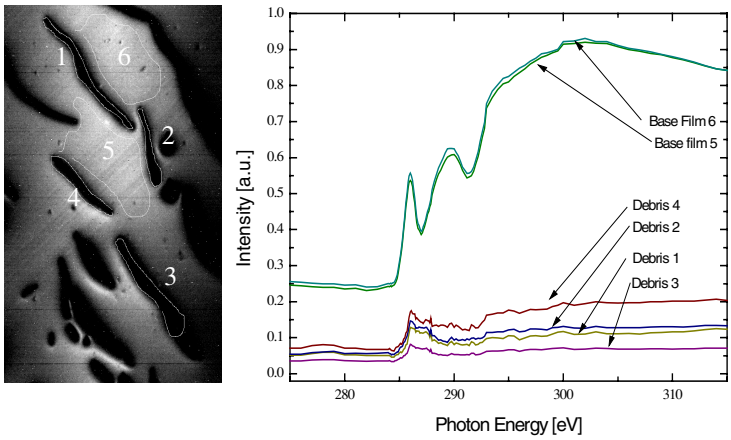
Friction behaviors of Si-incorporated DLC films in dry air and in vacuum are summarized in Fig.1.The friction behavior of the DLC films in dry air and in vacuum environment showed a clear difference, that is, lower and stable friction coefficient in dry air atmosphere and higher and fluctuated friction coefficient in vacuum. The higher the silicon content in the DLC film, the lower is the friction coefficient. In vacuum environment, higher fluctuation of the friction coefficient was observed all over the test cycle range.



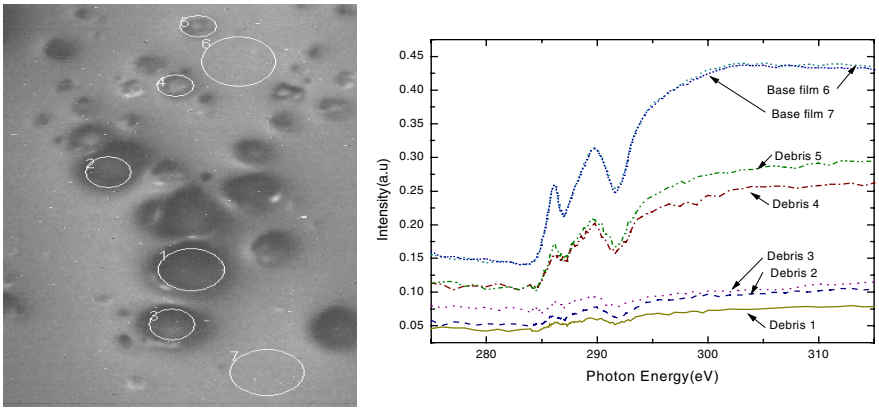
(a) **(b)**

Fig.1. Friction behavior of Si-incorporated DLC films in vacuum (a) and dry air (b).

PEEM images of the microstructures and NEXAFS spectra of the respective debris and base DLC films are summarized in Fig.2 for the two samples with Si content 0.5% tested in vacuum and 9.5% tested in dry air atmosphere. All the debris are spherical shaped except that of the low Si DLC film tested in vacuum. The debris of 0.5% Si DLC film exhibited elongated linear morphology which was found to be rolled bar shaped using SEM observation [6]. The NEXAFS spectra of this debris were completely different from the others. These spectra which have a π^* peak only and do not have any σ^* peaks, are very close to that of polymethylmethacrylate [7]. The high friction coefficient of the 0.5% Si-incorporated DLC film tested in vacuum is due to the tribochemical reaction from DLC to polymer and the resultant elongated debris shape change. Among the debris of the 9.5% Si-incorporated DLC film tested in vacuum, small portions were found to have elongated shape and the higher fluctuated friction coefficient of the DLC film tested in vacuum seems also to be due to this debris inclusion.



(a)



(b)

Fig.2. PEEM images and NEXAFS spectra of the Si-incorporated DLC films and the wear debris. (a) Si 0.5% DLC film and debris tested in vacuum. (b) Si 9% DLC film and debris tested in dry air.

The NEXAFS spectra of the base film and the other debris showed a broad intermediate peak between clear π^* bond peak (285eV) and high σ^* bonds hill peak (over 290eV). This intermediate peak is related to the mixture peak of C-H bonds and C=O bonds peaks. In the debris NEXAFS spectra of the films tested in dry air atmosphere, the σ^* bonds hill over 290eV in

the debris is lower than that in the base film and these peaks are related to C-O bonds and C=O bonds, which means that the debris is partially polymerized. These partially polymerized debris remains as finely dispersed spheres in the wear test in dry air atmosphere and the lower friction coefficient results seem to be mainly due to this debris behavior.

CONCLUSION

The morphology and the carbon K edge NEXAFS spectra of the Si-incorporated DLC films and the respective debris were investigated depending on the Si content and the tribological testing atmosphere, that is, vacuum or dry air atmosphere. The debris morphology and structure of the 0.5% Si-incorporated DLC film formed in vacuum were elongated linear and polymeric and these debris were partly included even in the 9.5% Si-incorporated DLC film. The friction behavior difference between dry air and vacuum came from the inclusion of elongated debris with polymeric structure formed during the wear test.

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